A REVIEW OF THE 1991 E760 RUN

M. Church

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I. Introduction

The 1991 E760 run was highly successful. This note is an attempt to record some important information regarding Accumulator operation during the run, so that it will be easily accessible for the next E760 run. The topics are not in any particularly relevant order, but are taken mostly from a seminar given by M. Church on 2/13/92. Much ramp data resides in the "E760 Ramps Notebook" and much other data resides in E760 logbooks V, VI, VII, and VIII.

II. Physics Results

I list here some of the more important physics results.

1) Discovery of the $1P_1$;
2) Measurement of the $\chi_2 \longrightarrow \gamma\gamma$ branching ratio;
3) Measurement of the J/Ψ and Ψ' full widths;
4) Further improvement on the measurement of the $\chi_2 \longrightarrow \Psi\gamma$ angular distribution functions;
5) Measurement of the $\bar{p}p \longrightarrow e^+e^-$ electromagnetic form factor;
6) Measurement of the $\bar{p}p \longrightarrow \bar{p}p$ elastic scattering parameter, ρ.

III. General Run Summary

Table 1 summarizes the data collected during the run. Fig. 1 shows the luminosity collected week by week and the average stacking rate per stack. Fig. 2 shows the luminosity integrated through the run. A total of 31 pb^{-1} was collected. Fig 3. shows a typical deceleration (above transition) with a typical efficiency of 95% . Early in the run the efficiency was very close to 100% . I suspect there was an aperture restriction – possibly a momentum aperture limitation as we wandered too close to the edge of the momentum aperture. The deceleration efficiency really should be 100% . Fig. 4 shows a typical data-taking cycle. The break point 2/3rds through the data-taking is a deceleration to the η_c. Fig. 4a and 4b show horizontal and vertical aperture as a function of momentum for the 1990 ramps and 1991 ramps as measured in Jan. 1991. During the run, the actual apertures were known to be smaller. The problem of radiation during stacking was solved during this run by the addition of more shielding. Fig. 4c shows the final layout of shielding blocks. A 40 mA stack gave about 3 mrads of radiation in the Pb-G as measured by standard chipmunks. The total amount of radiation received during the run was about 100 rads – bringing the total to about 200 rads for the Pb-G.

IV. Transition Crossing

Fig. 5 shows γ_T as a function of beam momentum. The γ_T jump is about 1 unit. Above transition, η is -.0075 and below transition η is .0058. Fig. 6 shows the transition-crossing efficiency and efficiency below transition. Transition crossing was typically 100% efficient (as much as 30 mA was taken across transition), but usually some beam was lost when bunching below transition due to the fact that we were so close to the edge of the momentum aperture there. This is undoubtedly because the quads mis-steer the beam during transition crossing. Below transition some beam was lost due to decreasing bucket area. ARF3 could not reliably hold 3 kV and had to be turned back to 2.8 kV later the run. The beam was cooled at POFTT=4434. There was some evidence of beam blowup crossing transition (Fig. 7), but not enough to lose beam out of the machine. Cooling below transition was effective (but slow), and when the beam got too small in $\Delta p/p$ the transverse emittances started to grow uncontrollably. Fig. 8 shows the effect of cooling below transition. For the next run a strong effort should be made to keep the beam centered in the quads so that transition crossing does not distort the orbit so much.

V. Beam Lifetime

The beam lifetime was generally very good. Figs. 9 and 10 show Accumulator vacuum plots with gas jet on and off. Fig. 11 shows the effect on the beam lifetime of turning on the gas jet. Depending on the gas jet pressure, lifetimes at the $1P_1$ varied from 65 hours to 100 hours. The beam lifetime can be calculated reasonably accurately from 1st principles. The 4 major contributors to the lifetime are:

1) Hard nuclear scattering in the H_2 gas jet;
2) Coulomb scattering from the the H_2 nuclei;
3) Scattering from atomic electrons in the H_2 gas jet;
4) Everything else.

Typical parameters are:
$P_{beam} = 6500$ Mev/c
Z = A = 1
gas jet density (ρ) = .5 x 10^{14} atoms/cm^2
$I_{beam} = 30$ mA
$\sigma_T = 68$ mb (total cross section)
$L_0 = 9.3 \times 10^{30}\ cm^{-2}sec^{-1}$ (luminosity)
$dE/dx = 4.12\ Mev/g/cm^2$

The total lifetime is given by

$$1/L = 1/L_\sigma + 1/L_c + 1/L_{dE/dx} + 1/L_e. \quad (1)$$

Since the loss rate for each of these processes is proportional to the number of antiprotons in the ring, the lifetime due to any single process is simply $L_i = N_{\bar{p}}/R_i$, where R_i is the loss rate for that process.

The total cross section for hard scattering is 68 mb, therefore for the above parameters

$$L_\sigma = N_{\bar{p}}/(L_0\sigma_T) = 132 \text{ hours.} \quad (2)$$

As long as the betatron cooling system has adequate power to contain the emittance, then the losses due to coulomb scattering from the H_2 nuclei will be dominated by individual large scatters. The probability of such a scatter between θ and $d\theta$ is given by the Rutherford scattering formula:

$$P(\theta)d\theta = \frac{52.3 \times 10^{-26} F_0 Z^2 \rho_{H2}}{(\beta pc)^2} \frac{d\theta}{\theta^3} \quad (3)$$

For the A50 sector of the Accumulator $\beta = 8$ meters and the aperture was typically 6π, therefore

$$\theta_{max} = \sqrt{6\pi/8} = .85mr. \quad (4)$$

Integrating eq. 3 from θ_{max} to ∞ gives a lifetime of $L_c = 750$ hours.

As with coulomb scattering, as long as the momentum cooling can overcome the average dE/dx loss in the gas jet, then beam losses due to scattering with atomic electrons will be dominated by individual large energy transfer scatters. The number of electrons scattered between kinetic energies T and dT is given by

$$dN = 15.8 \times 10^{-20} \frac{N_0 Z \rho_{H2}}{\beta^2} (1 - \frac{\beta^2 T}{T_{max}}) \frac{dT}{T^2} \quad (5)$$

The largest allowable T is determined by the geometry of the momentum cooling pickups. For the 4-8 Ghz system, about 12 mm from the center of the pickups the phase of the cooling signal changes sign (private communication from D. McGinnis) and cooling is no longer effective. For a lattice dispersion function of 9 meters, this corresponds to $T = 8$ Mev at a beam momentum of 6500 Mev/c. Integrating eq. 5 from 8 Mev to T_{max} gives $L_{dE/dx} = 500$ hours.

The remainder of the lifetime is simply the lifetime with the gas jet off. This was typically 500 hours at 6500 Mev/c. Adding up these 4 contributions gives a calculated beam lifetime of 77 hours at 6500 Mev/c. The actual beam lifetime was 65 hours, which is in reasonably good agreement with the calculation. The basic formulas for the above calculations can be found in Rossi, "High Energy Particles".

VI. Orbit Length Measurement

A detailed discussion of the orbit length measurement is contained in S. Werkema's soon-to-be-released pbarnote. Fig. 12 shows a typical difference orbit compared with the P85 fit. Typical P85 "chisqr" was .6, however during the course of the run this gradually got worse, presumably from a deteriorating BPM system, and was typically 1.6 near the end of the run.

VII. Beam Energy Drift

Figs. 13 and 14 shows the accumulator magnetic field, LCW temperatures, and tunnel (magnet) temperature as a function of time during a typical data-taking period. When stacking stopped, the debuncher and beamlines were turned off to save power and then the beam was decelerated to the operating point. These actions reduced the power consumption in the tunnel from about 2 MW to about .5MW. The LCW temperature feedback system was not able to handle this, and as a result the temperature changed dramatically in the tunnel – causing the magnetic field to change – probably due to the coefficient of thermal expansion of the magnets. This in turn caused the energy to slowly drift (since the beam was slightly bunched). The 4-8 Ghz momentum cooling system, at the low power levels used, did not keep the beam exactly centered under the pickups, and hence the beam position changed. This is shown in Fig. 15, along with the relevant equations. Drifts of about 2-3 mm over the course of a $1P_1$ point were typical. Typically in the middle of such a data-taking cycle, the beam energy had to be moved by hand to keep it near the original energy point. Total energy drift (without changing by hand) was usually about 400 Mev in the center of mass. It was suspected that the apparent magnetic field change might be due to temperature variations on the magnet shunts, but the magnet with the NMR probe was used with and without a shunt and the apparent field change exhibited no difference. In addition, it was suspected that the beam pipe (and BPM's and 4-8 Ghz pickups) were actually moving – but this was tested with LVDT's mounted at various places in the ring and found not to be true. However, the measured magnetic field change only amounted to about 1/2 as much as predicted by the measured orbit length change, and this is still not understood.

VIII. Beam Stability

Transverse and longitudinal beam blowups were occasionally observed – they were usually explainable by failed equipment or incorrect operating procedure. It was noted that bunching the beam with a small ARF3 voltage usually stabilized the transverse emittances (see Fig. 16). This is tentatively explained as an ion-clearing mechanism. Fig. 17 shows the transverse emittances during a typical data-taking cycle (beam current going from 40 mA to 10 mA). It is currently believed the horizontal emittance monitor is miscalibrated by a factor of 1.5. Emittances could have easily been forced lower, however doing so did not improve the luminosity and could have developed instabilities. The damper pickup signal provided some diagnostics, and could be correlated with other beam events. Clearing electrode currents could also be correlated with beam events (turning on gas jet, emittance blowups, spikes in damper pickup signal). Catastrophic transverse emittance blowup was observed to occur if the beam was cooled too much longitudinally. At $\eta = .014$, $P_{beam} = 5800$, and I = 35mA, the stability theshold was measured to be at approximately $\Delta P/P = 4.4 \times 10^{-4}$ (FWHM). Using the Keil-Schnell inequality,

$$|\frac{Z}{n}| < \frac{\eta E_{beam}}{I_{beam}}(\frac{\Delta P}{P})^2, \qquad (6)$$

we get a Z/n for the Accumulator of 450Ω. This includes ARF3 (350Ω) but not ARF1, which was shorted out. We ran typically at 15-20% above this threshold.

1991 RUN SUMMARY

PHYSICS	RUN #'s	DATES	POFTT	ECM	INT LUM (nb-1)	STCK
1st J Rosen	1009-1019	7/13	6829.0	3840.6	125	125
J/Psi DS	1021-1071	7/15- 7/19	4033.8-4027.4	3095.5-3097.8	401	401
Psi' DS	1074-1132	7/22- 7/27	6196.2-6204.7	3686.5-3684.2	995	995
2nd J Rosen	1133-1136	7/30	6877.8	3852.8	86	
1st Chi2	1137-1170	7/31- 8/02	5694.6	3555.5-3557.1	797	883
Psi' bckgrnd	1171-1189	8/08- 8/10	6126.2	3667.5	369	369
1st 1P1	1190-1215	8/12- 8/15	5571.9-5572.8	3524.2-3524.8	823	823
3rd J Rosen	1216-1217	8/17	6786.0	3830.6	85	
2nd Chi2	1218-1234	8/17- 8/20	5694.9	3556.2	706	
J/Psi bckgrnd	1235-1240	8/20	3871.7	3049.9	87	878
2nd 1P1	1242-1263	8/21- 8/24	5570.9	3524.0	783	783
4th J Rosen	1266-1267	8/26	6929.0	3865.0	89	
3rd Chi2	1268-1287	8/26- 8/29	5695.0	3556.1	1072	
J/Psi peak	1288-1291	8/29- 8/30	4031.0	3097.0	64	1225
3rd 1P1	1293-1318	9/02- 9/06	5566.6-5565.0	3522.5-3522.9	980	980
p-pbar @ 8834	1319-1325	9/10- 9/13	8834.0	4273.4	333	313
1st etac'	1327-1346	9/16- 9/19	5842.0	3593.8-3594.3	827	827
4th 1P1	1350-1365	9/21- 9/23	5568.0	3522.9-3523.2	489	489
2nd etac'	1367-1390	9/26- 9/29	5926.0	3615.5-3616.0	1295	1295
3rd etac'	1391-1408	10/02-10/05	5916.0	3612.5-3612.9	1167	1167
4th etac'	1409-1421	10/06-10/08	5937.0	3618.7-3619.1	575	575
5th 1P1	1422-1441	10/10-10/13	5575.0	3524.8-3524.9	1041	1041
5th etac'	1442-1460	10/15-10/18	5947.0	3620.8-3621.3	1216	1216
6th 1P1	1461-1487	10/20-10/24	5579.0	3525.8-3526.3	1337	1337
6th etac'	1491-1502	10/26-10/29	5830.0	3590.6-3590.0	924	
etac bckgrnd	1503-1506	10/29-10/30	3418.0	2911.3	53	977
7th 1P1	1507-1533	11/02-11/06	5577.0	3525.3-3525.6	1310	
etac bckgrnd	1534-1544	11/06-11/07	3543.0	2950.1	197	1507
1st etac	1545-1551	11/09-11/10	3639.0	2979.2	165	165
8th 1P1	1553-1575	11/12-11/16	5580.0	3525.8-3526.1	1364	
2nd etac	1576-1588	11/16-11/19	3645.0	2981.1	393	1757
9th 1P1	1592-1618	11/24-11/27	5581.0	3526.3-3526.5	1083	1083
10th 1P1	1620-1636	11/29-12/01	5580.0	3525.9-3526.2	1017	
3rd etac	1637-1644	12/01-12/02	3687.0	2993.9	309	1326
11th 1P1	1645-1660	12/04-12/07	5583.0	3526.9-3527.1	1016	
4th etac	1661-1666	12/07-12/08	3658.0	2985.3-2985.4	200	1216
12th 1P1	1667-1682	12/11-12/14	5578.0	3525.7-3525.8	885	885
p-pbar @ 8834	1683-1685	12/17-12/17	8834.0	4272.2	300	
13th 1P1	1686-1701	12/17-12/19	5580.0	3526.0-3526.2	941	
2nd J/Psi DS	1702-1734	12/20-12/24	4034.0-4028.5	3098.2-3096.4	626	1880
14th 1P1	1735-1747	12/25-12/28	5579.0	3525.8-3526.0	980	
5th etac	1748-1756	12/28-12/30	3625.0	2974.9	424	1404
15th 1P1	1758-1771	12/31-01/02	5581.0	3526.2-3526.4	911	
6th etac	1772-1781	01/02-01/05	3674.0	2489.4-2489.6	513	1424
16th 1P1	1782-1796	01/06-01/08	5580.0	3525.9-3526.1	876	
7th etac	1797-1896	01/08-01/10	3724.0	3004.9	472	1348
TOTAL AS OF 01/10					30701	

Table 1: 1991 Run Summary

WEEK		INT LUM (nb-1)	RUNS
1	6/30- 7/06	0	
2	7/07- 7/13	125	1009-1019
3	7/14- 7/20	401	1021-1071
4	7/21- 7/27	995	1074-1132
5	7/28- 8/03	883	1133-1170
6	8/04- 8/10	369	1171-1189
7	8/11- 8/17	1057	1190-1222
8	8/18- 8/24	1427	1223-1263
9	8/25- 8/31	1225	1266-1291
10	9/01- 9/07	980	1293-1318
11	9/08- 9/14	333	1319-1325
12	9/15- 9/21	874	1327-1351
13	9/22- 9/28	1661	1352-1389
14	9/29-10/05	1243	1390-1408
15	10/06-10/12	1487	1409-1439
16	10/13-10/19	1345	1440-1460
17	10/20-10/26	1449	1461-1492
18	10/27-11/02	1010	1493-1510
19	11/03-11/09	1414	1512-1546
20	11/10-11/16	1589	1547-1580
21	11/17-11/23	281	1581-1588
22	11/24-11/30	1877	1592-1632
23	12/01-12/07	1691	1633-1664
24	12/08-12/14	942	1665-1682
25	12/15-12/21	1576	1683-1719
26	12/22-12/28	1449	1720-1750
27	12/29-01/04	1674	1751-1781
28	01/05-01/11	1348	1782-1805

Table 1: continued 1991 Run summary

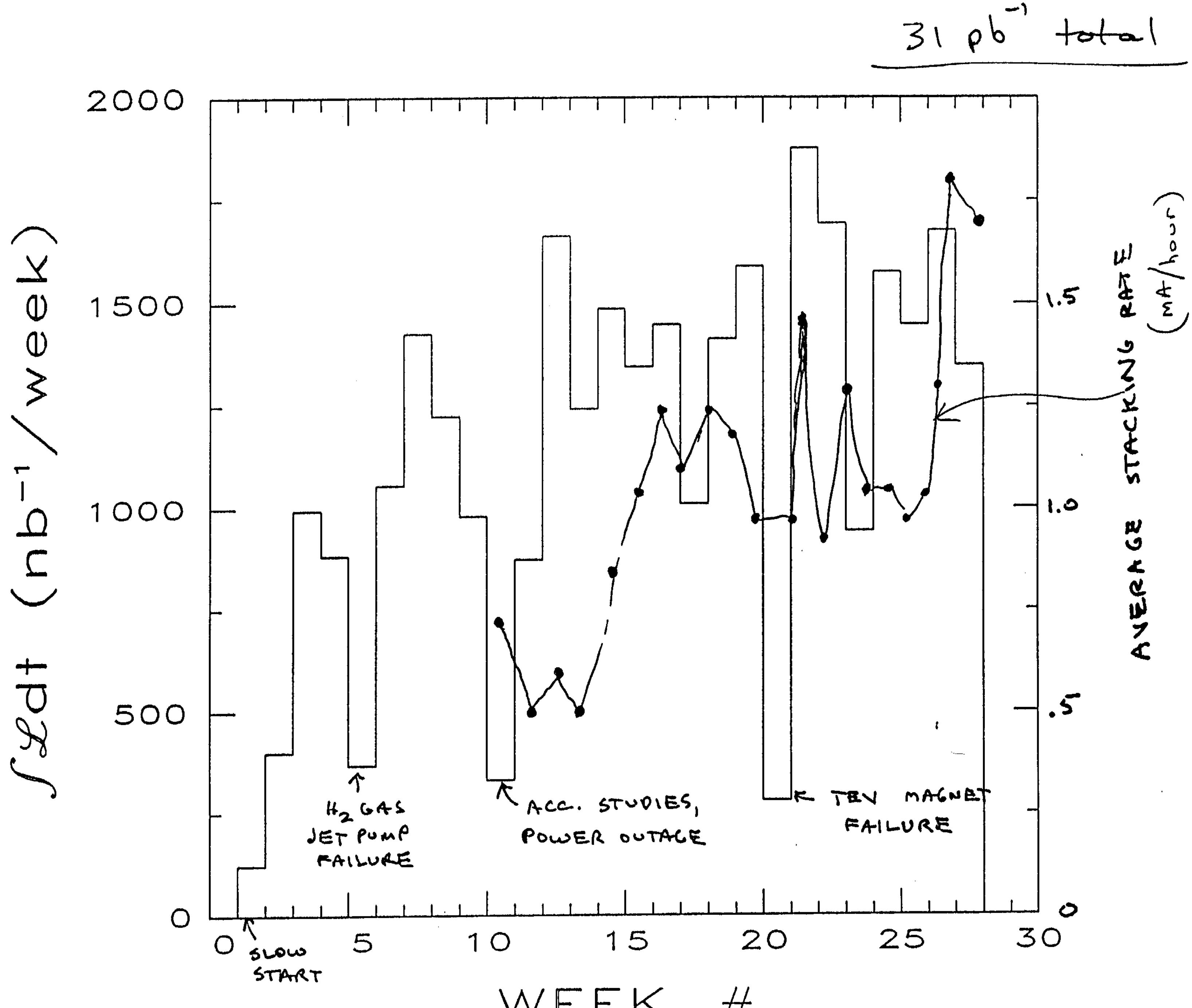


Fig. 1 1991 Luminosity summary

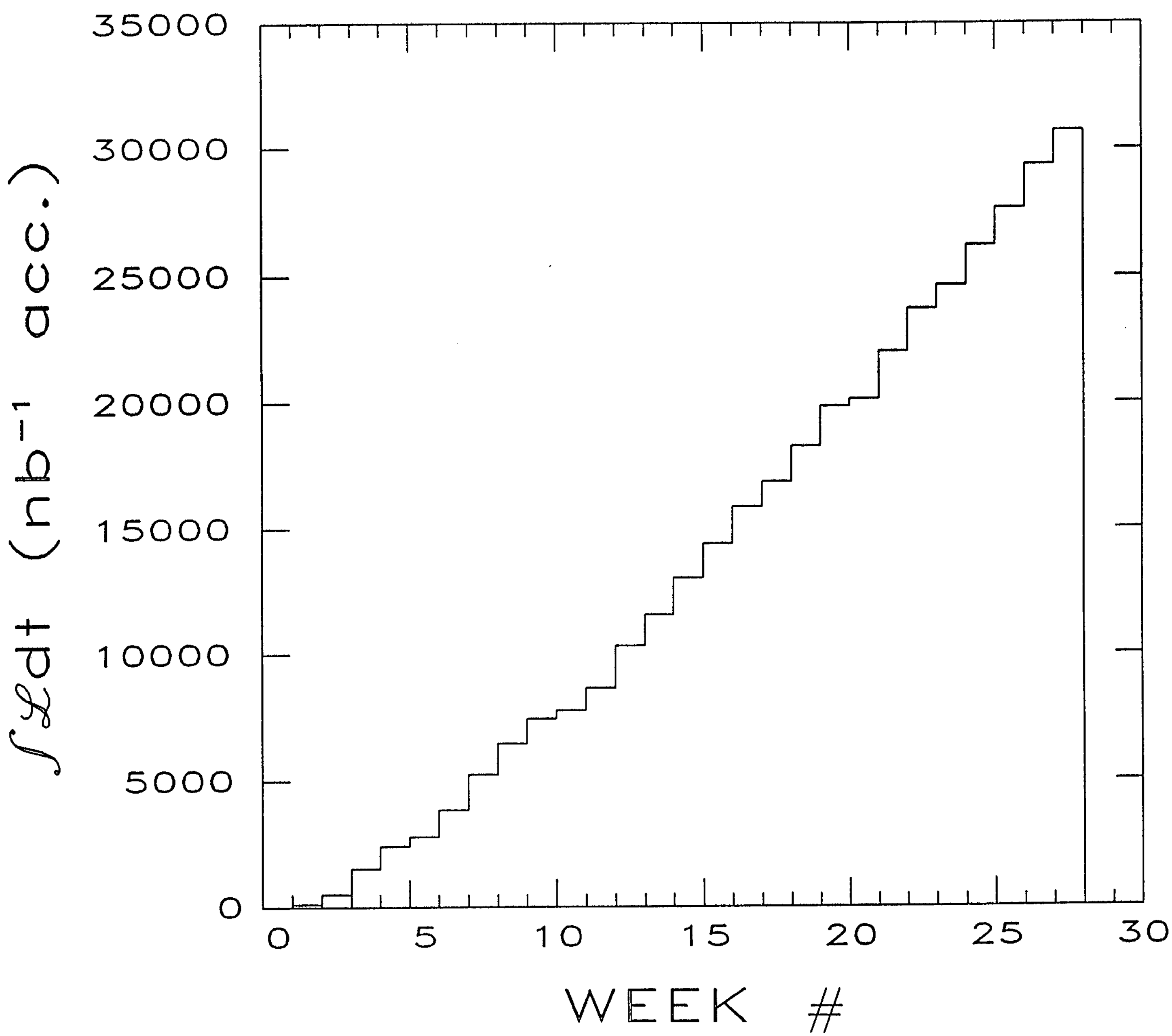
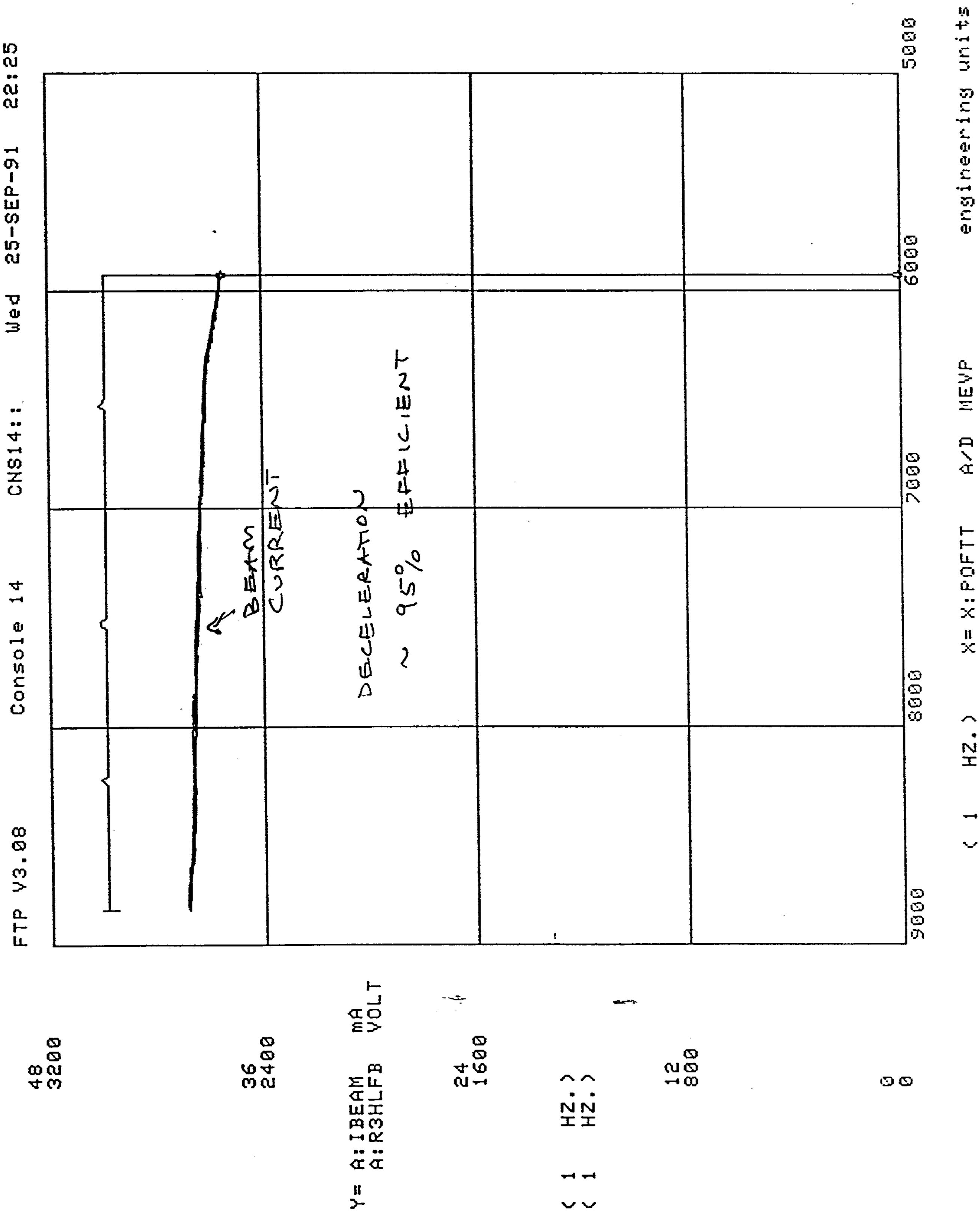


Fig. 2 1991 Integrated luminosity

CONSOLE LOCATION 14; AP10 25-SEP-1991 22:36
Fast Time Plot



Deceleration for 2nd η_c' point

Fig. 3

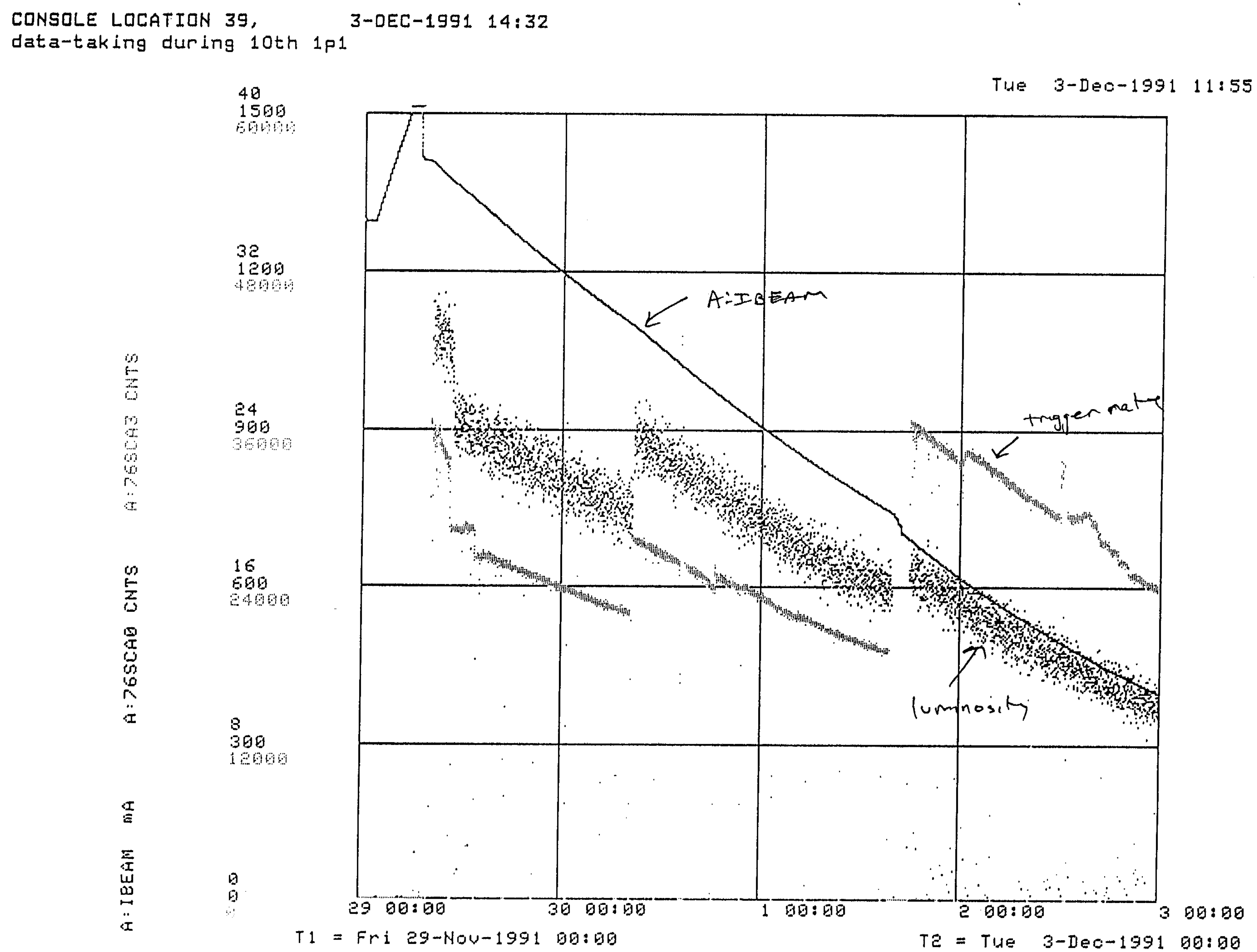


Fig. 4. Typical data-taking cycle

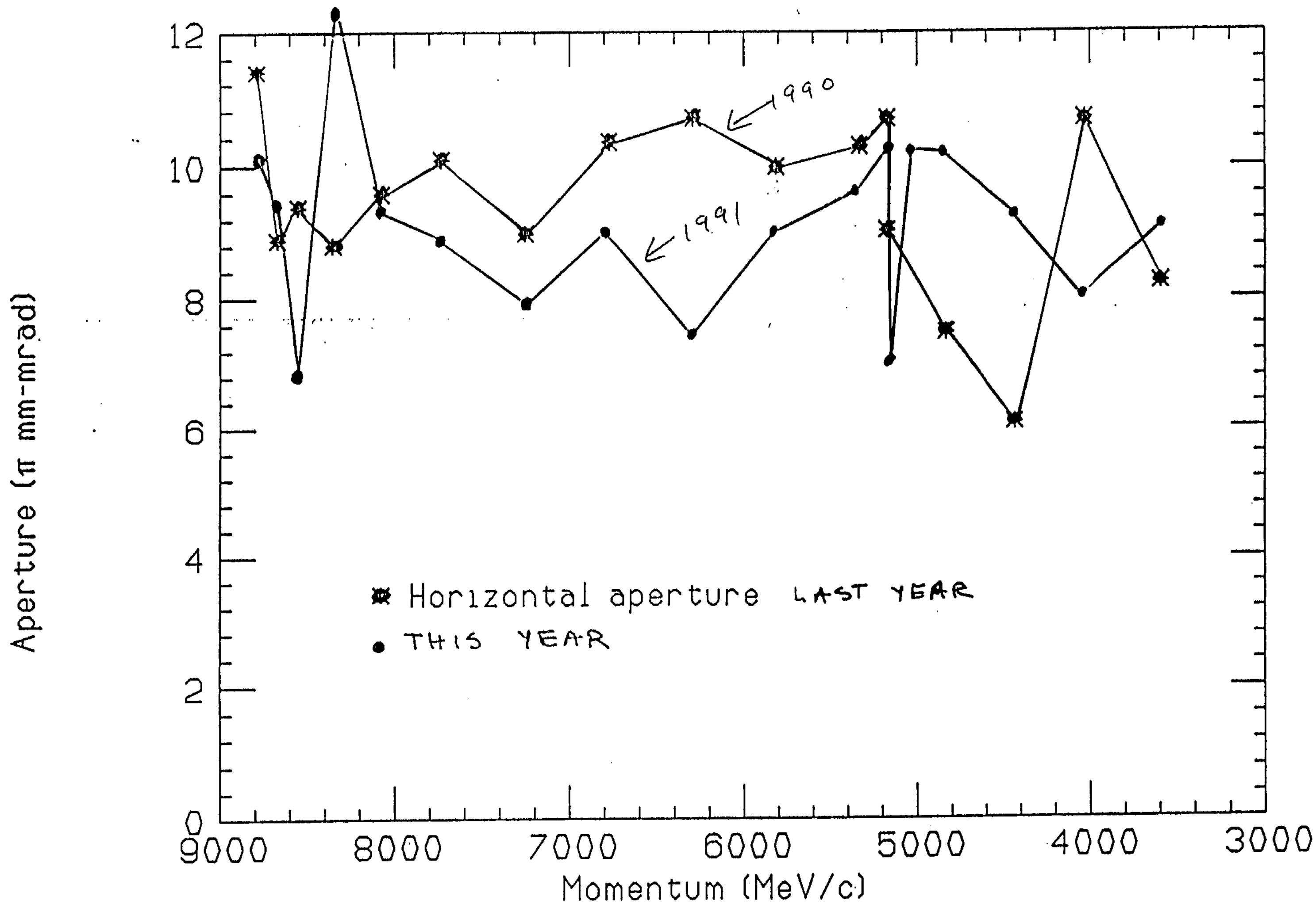


Fig 4a) Horizontal aperture vs. momentum

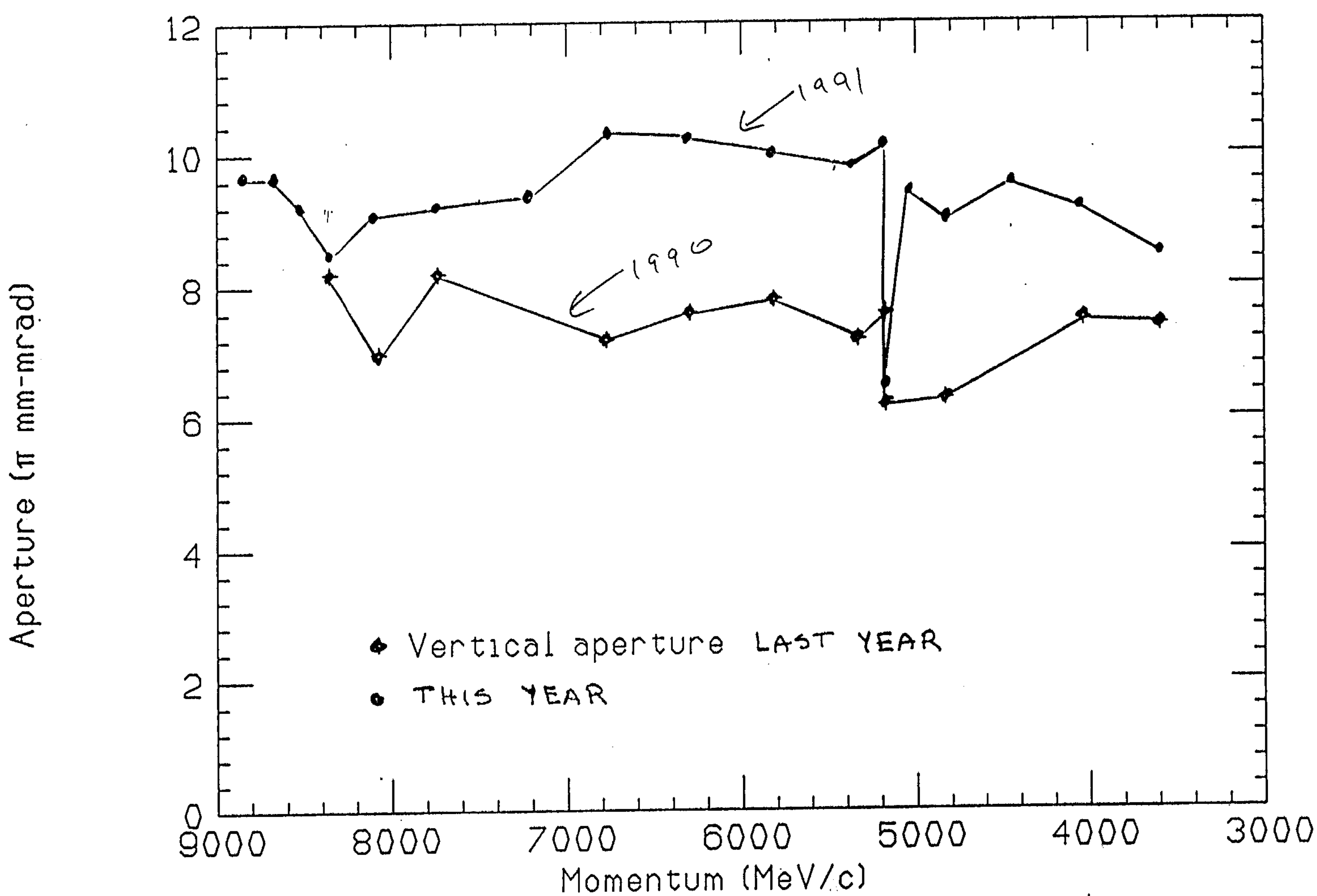
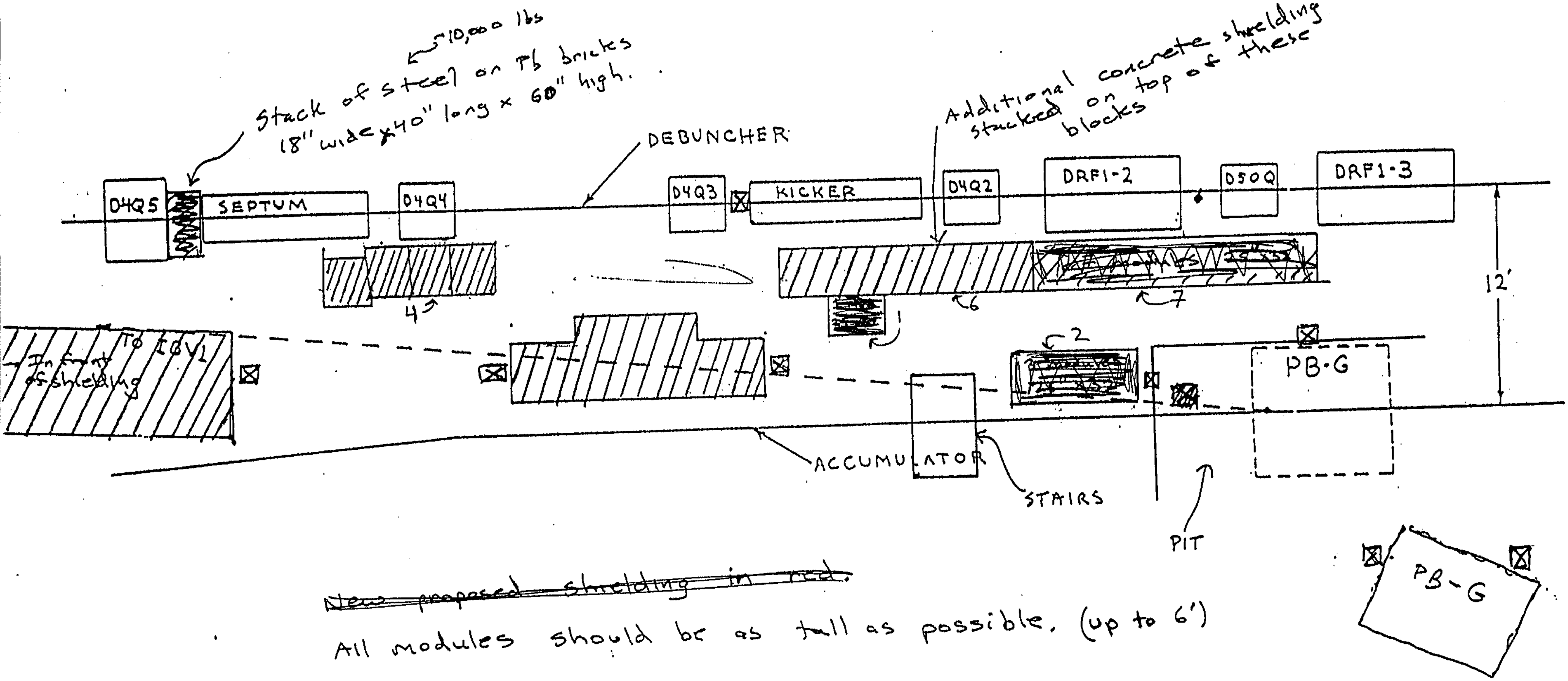


Fig. 4b Vertical aperture vs. momentum.

Proposed Additional Shielding for E760

M. Church 1/14/91



~~New proposed shielding in red.~~

All modules should be as tall as possible. (up to 6')

11 new modules + 1 "stack" behind D4Q5.

Fig 4c: - Radiation shielding for E760

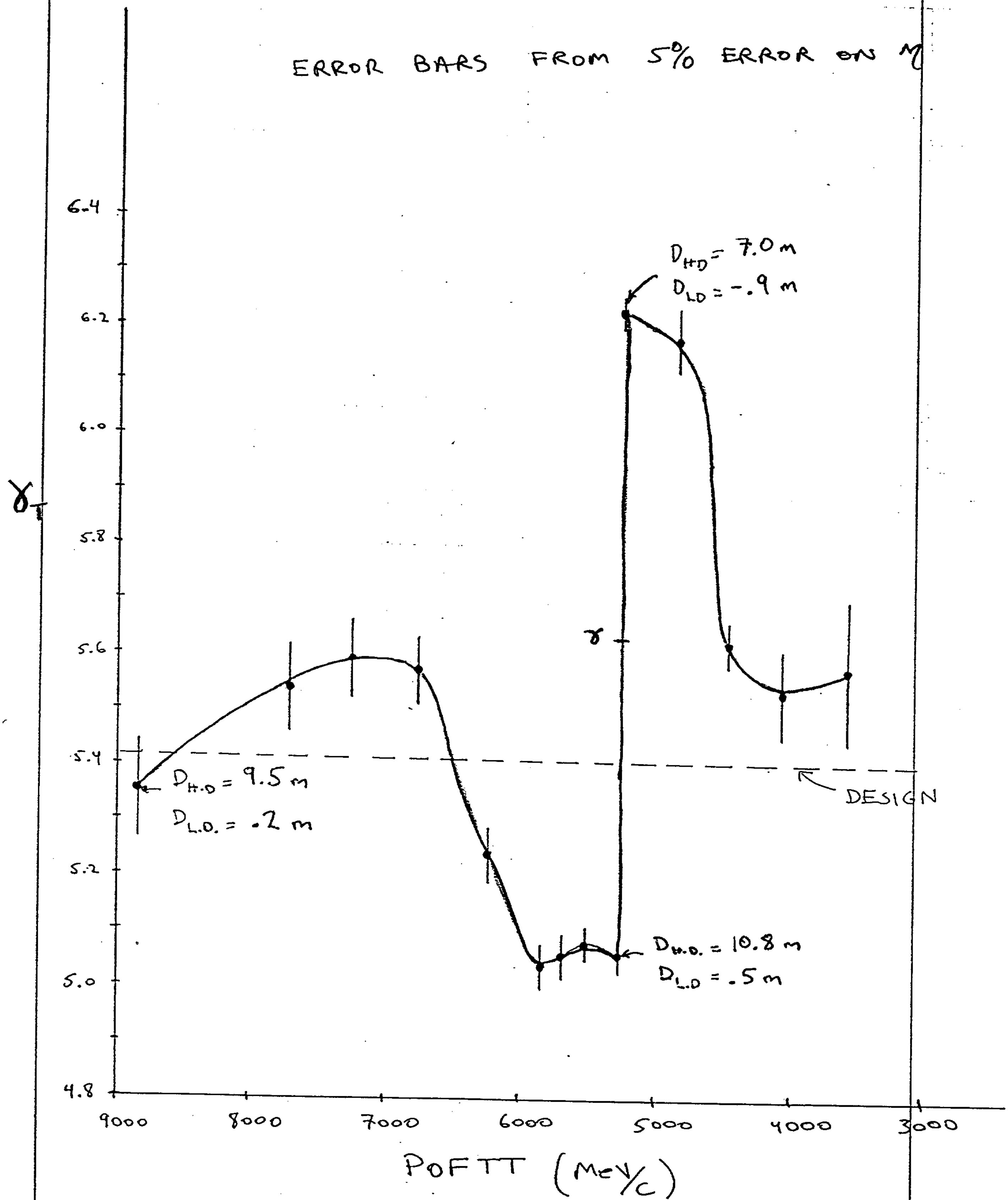


Fig-5 γ_T as a function of beam momentum

CONSOLE LOCATION 17, MCR-W2   16-NOV-1991 14:45
deceleration from 5580 to 3645

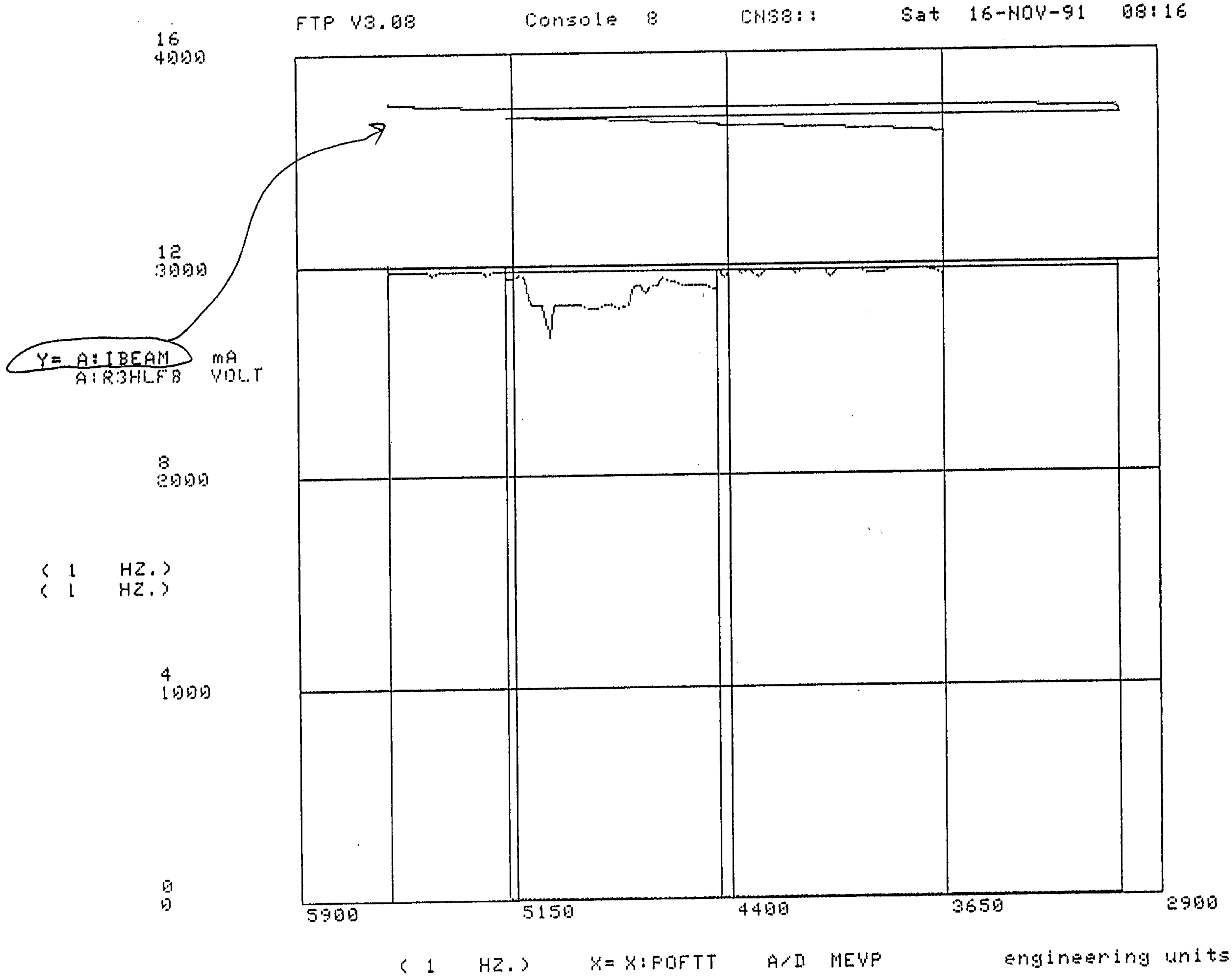


Fig. 6 Transition crossing efficiency and below transition deceleration efficiency.

CONSOLE LOCATION 15, AP10 2-SEP-1991 11:54

[redacted] Longitudinal Schottky 10 mA

Ref Lvl -20 dB

08/29/91 1737

Scale 10 dB/div

Atten 10 dB

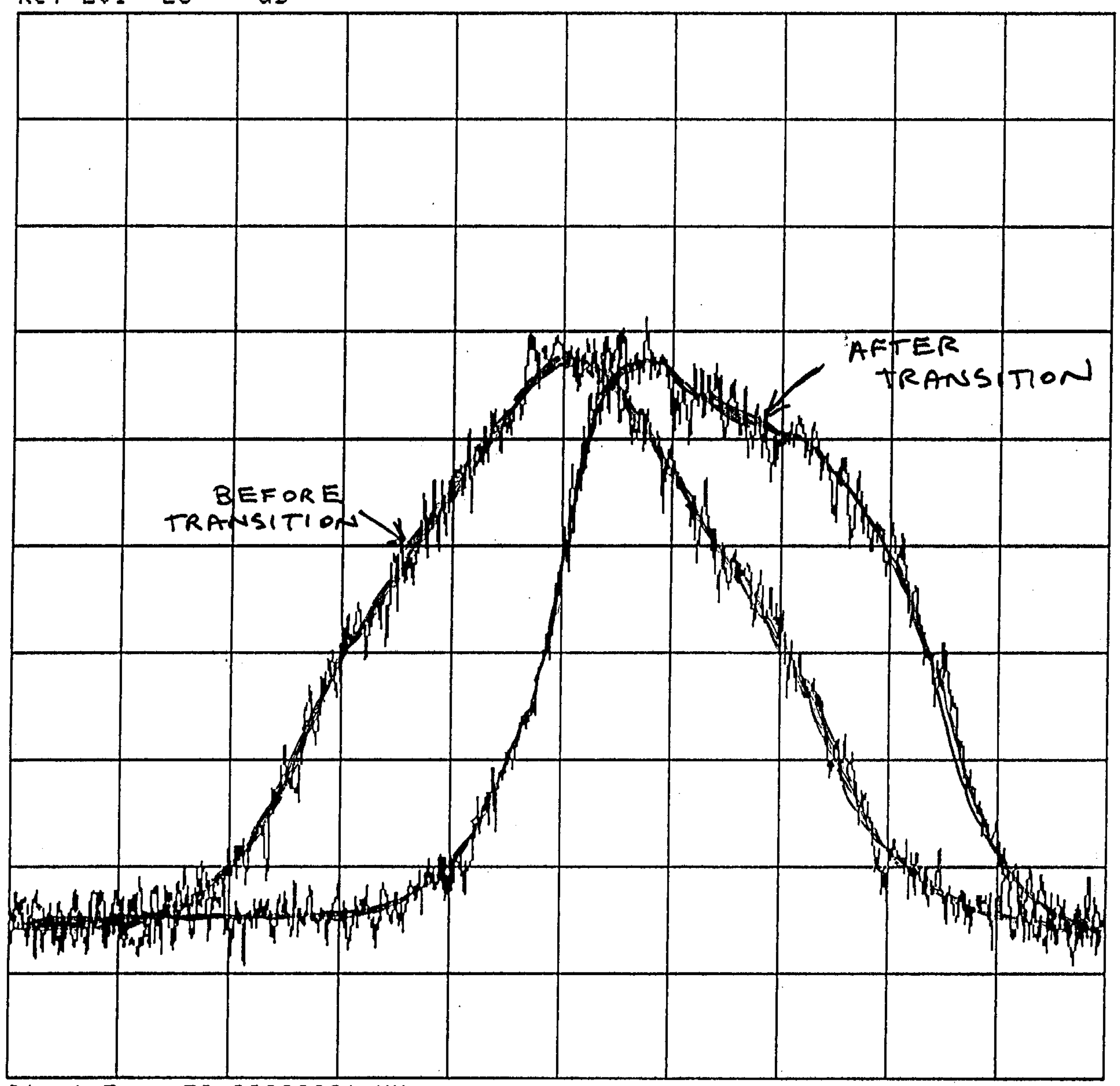
Swp 10 sec

Vid BW 10 Hz

Res BW 100 Hz

$\eta = -.0075$

$\eta = .0058$



Start Freq 79.03829001 MHz

Stop Freq 79.04329001 MHz

← 5 kHz span →

Fig. 7. Longitudinal Schottky before and after transition crossing

CONSOLE LOCATION 15, AP10 2-SEP-1991 11:55

cooling below transition Longitudinal Schottky

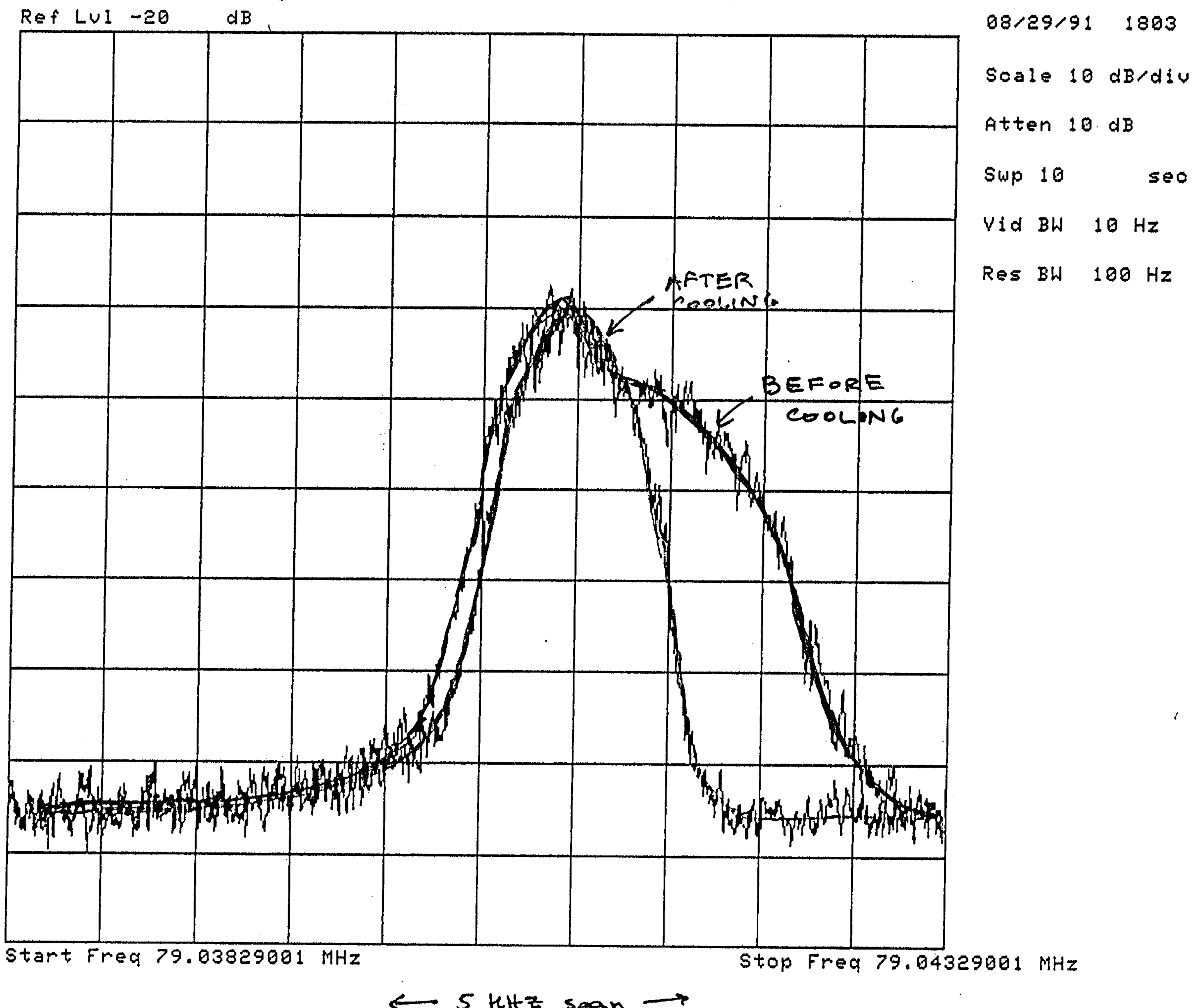


Fig. 8. Cooling below transition

CONSOLE LOCATION 14; AP10 9-JAN-1992 18:22

ACCUMULATOR PRESSURE PROFILE 01/09/92 1821

AVERAGE PRESSURE (ION PUMPS) = 1.828E-08 (ION GAUGES) = $\boxed{3.062E-09}$

GAS JET ON

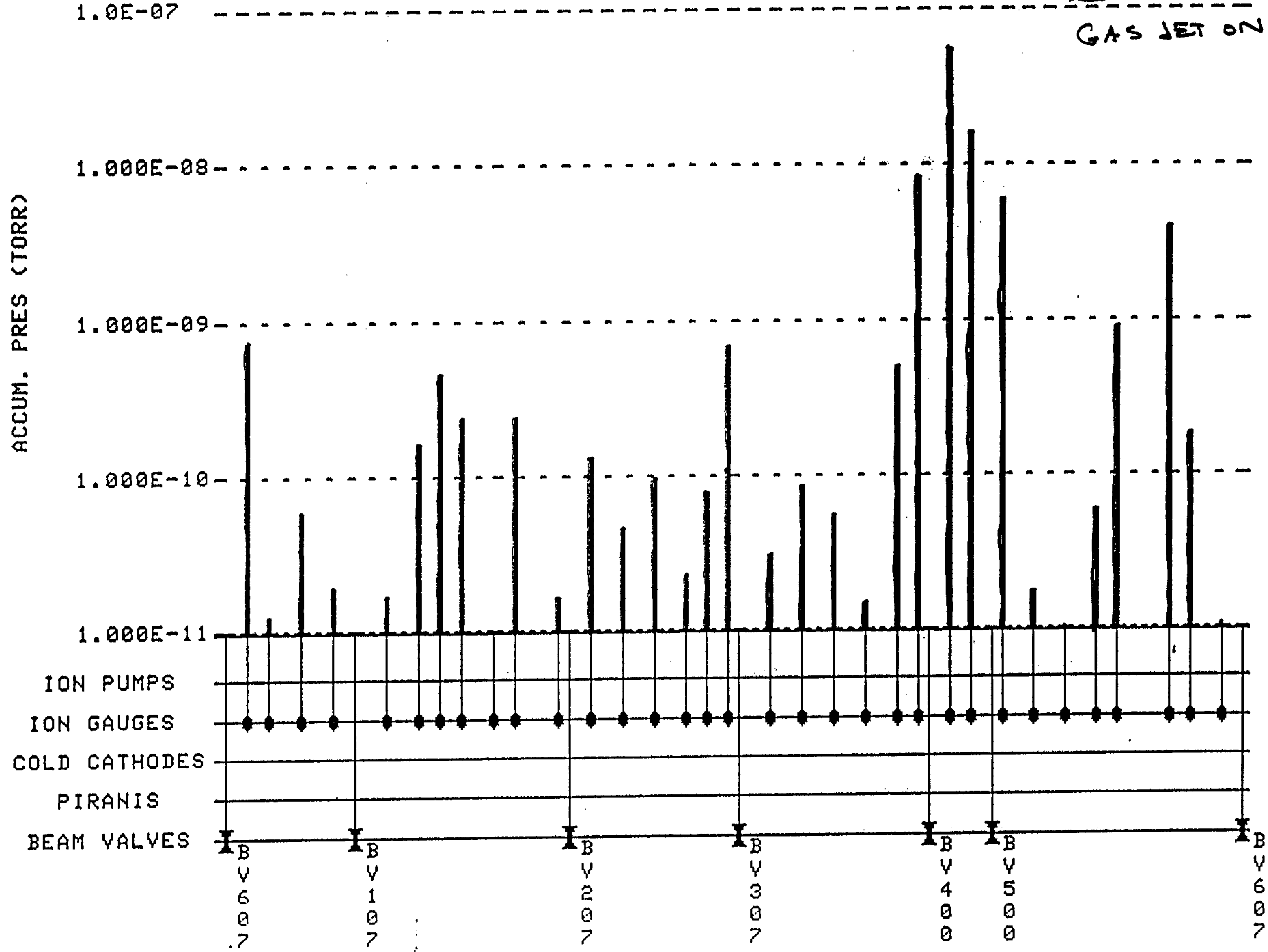


Fig 9: Acc. Vacuum Gas Jet ON

CONSOLE LOCATION 43;   16-SEP-1991 10:28
Untitled

29.6 mA, jet off after stacking for Mc'

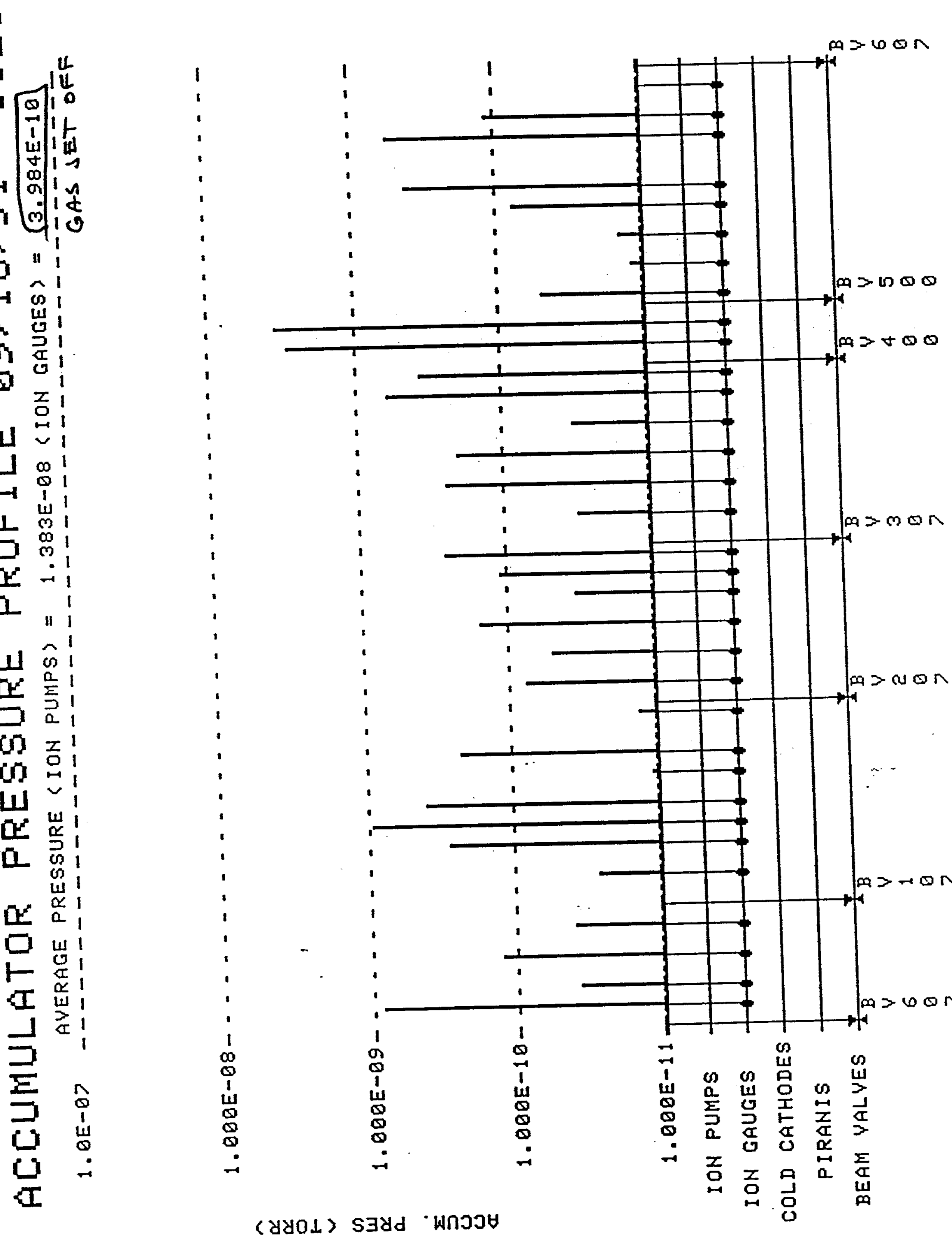


Fig 9. Acc. Vacuum, Gas jet off

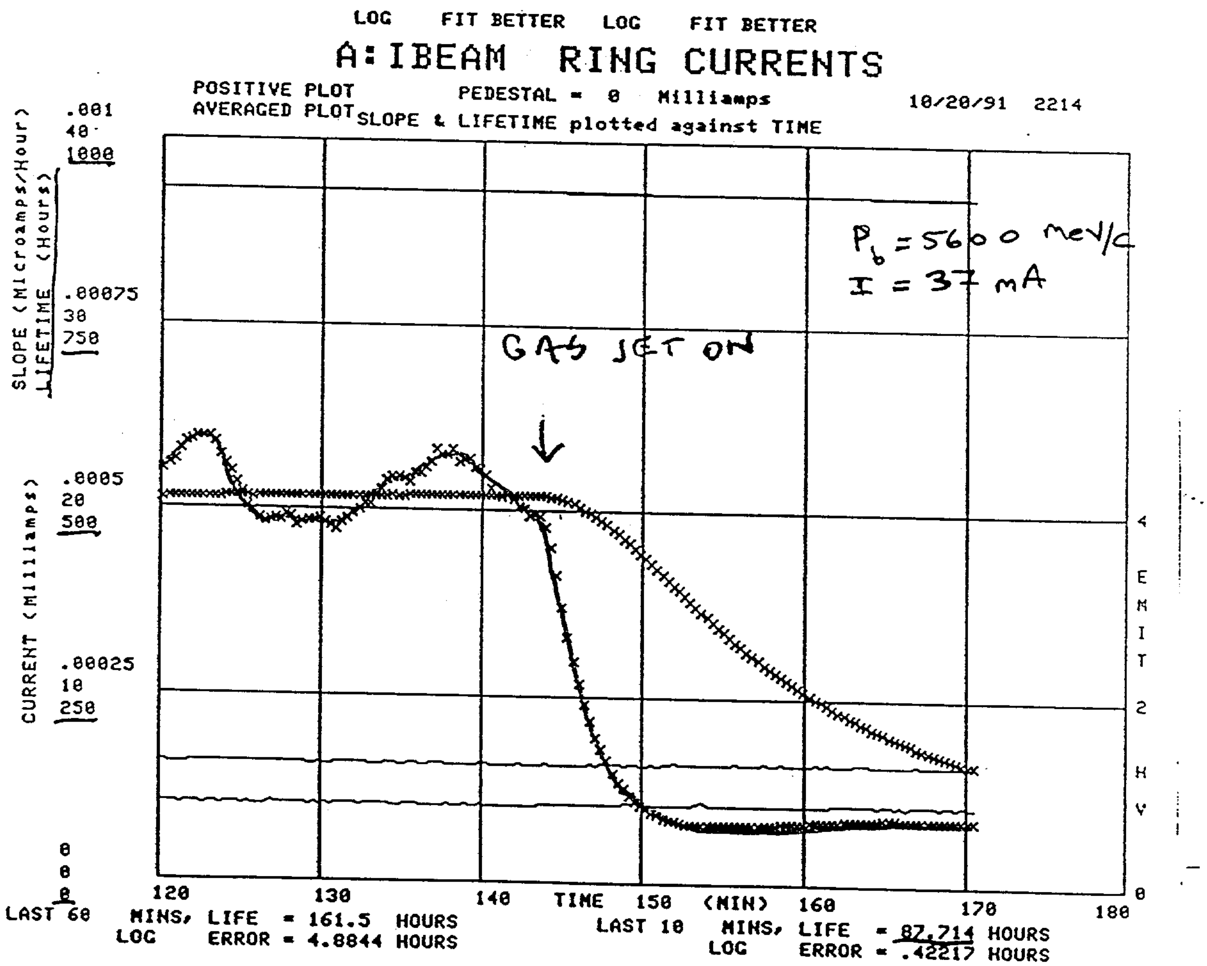
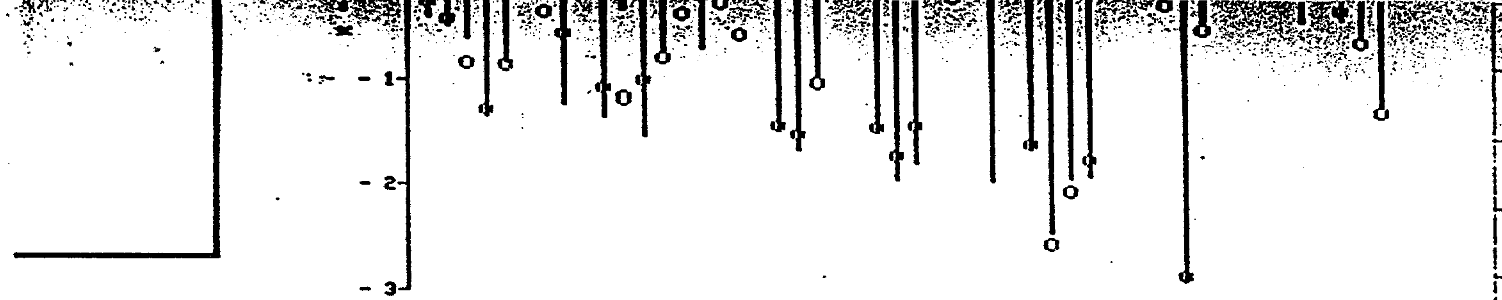


Fig 11: Effect on lifetime of gas jet.



31 gives rise to a poor fit. ~~Go~~ Going

♦FTP♦ ♦COPIES♦

splays

lculation
y Kicks (LEX)
y Fit (LEX)
y Raw Data (SS)
ES Kicks: .3 mrad
Fit: 3 mm

ffset
le 30

HORIZONTAL X - Xref

Reference File: 3 09/16/91 0922 PSI' BS91 AVE OF 5TH CTR PT- REF
Lattice File : 2 07/31/91 1723 POFTT=5035. ETAC PRIME. THR=.01

$\boxed{\text{chisqr = .6330386}}$

A1Q1	-.13	A2Q14	-.77	A3Q1	-1.25	A4Q14	1.23	A5Q1	.03	A6Q14	-.76
A1Q3	-.31	A2Q11	-.31	A3Q3	-1.51	A4Q11	.96	A5Q3	.56	A6Q11	.78
A1Q4	-.5	A2Q10	-.53	A3Q4	-.62	A4Q10	-.52	A5Q4	.09	A6Q10	-.75
A1Q6	-1.11	A2Q8	-.49	A3Q6	1.33	A4Q8	1.89	A5Q6	-2.97	A6Q8	-.73
A1Q8	-.49	A2Q6	.07	A3Q8	1.13	A4Q6	-1.43	A5Q8	-.27	A6Q6	-1.44
A1Q10	.12	A2Q4	-.36	A3Q10	-.96	A4Q4	-2.13	A5Q10	.91	A6Q4	-.07
A1Q11	-.09	A2Q3	.04	A3Q11	-2.3	A4Q3	-1.63	A5Q11	1.23	A6Q3	.45
A1Q14	-.72	A2Q1	.15	A3Q14	-1.51	A4Q1	-1.53	A5Q14	1.61	A6Q1	.24

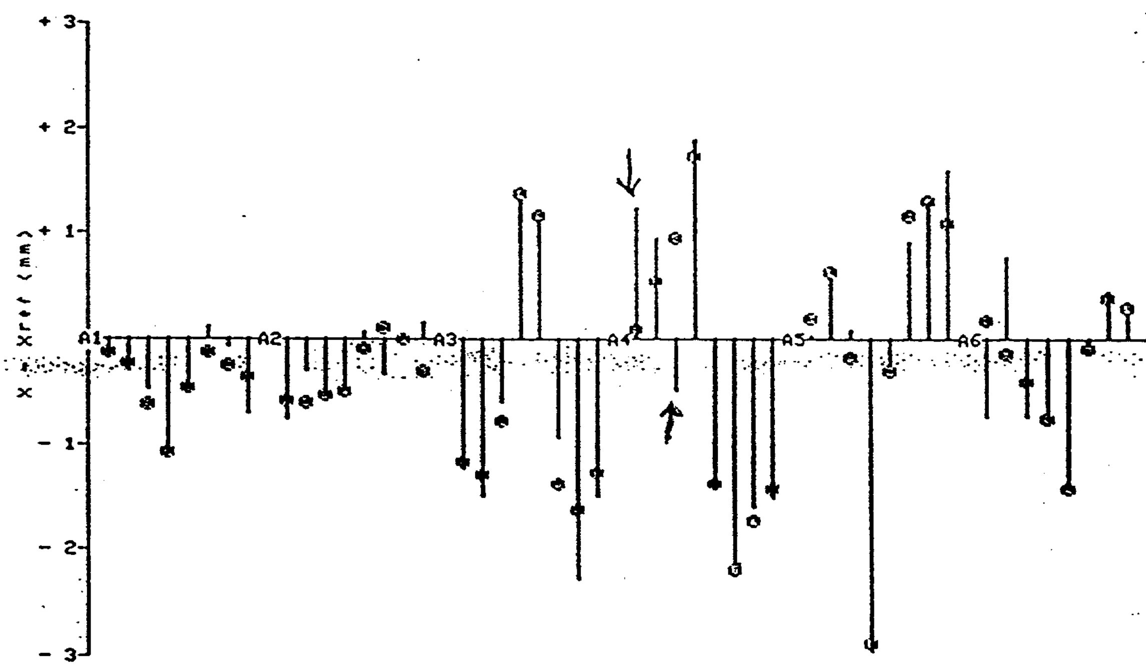


Fig. 12 Difference orbit with PB5 fit.

~~still do not read out well compared~~

CONSOLE LOCATION 43,   11-OCT-1991 00:43
Lumberjack Plot   MCR   A:BFIELD

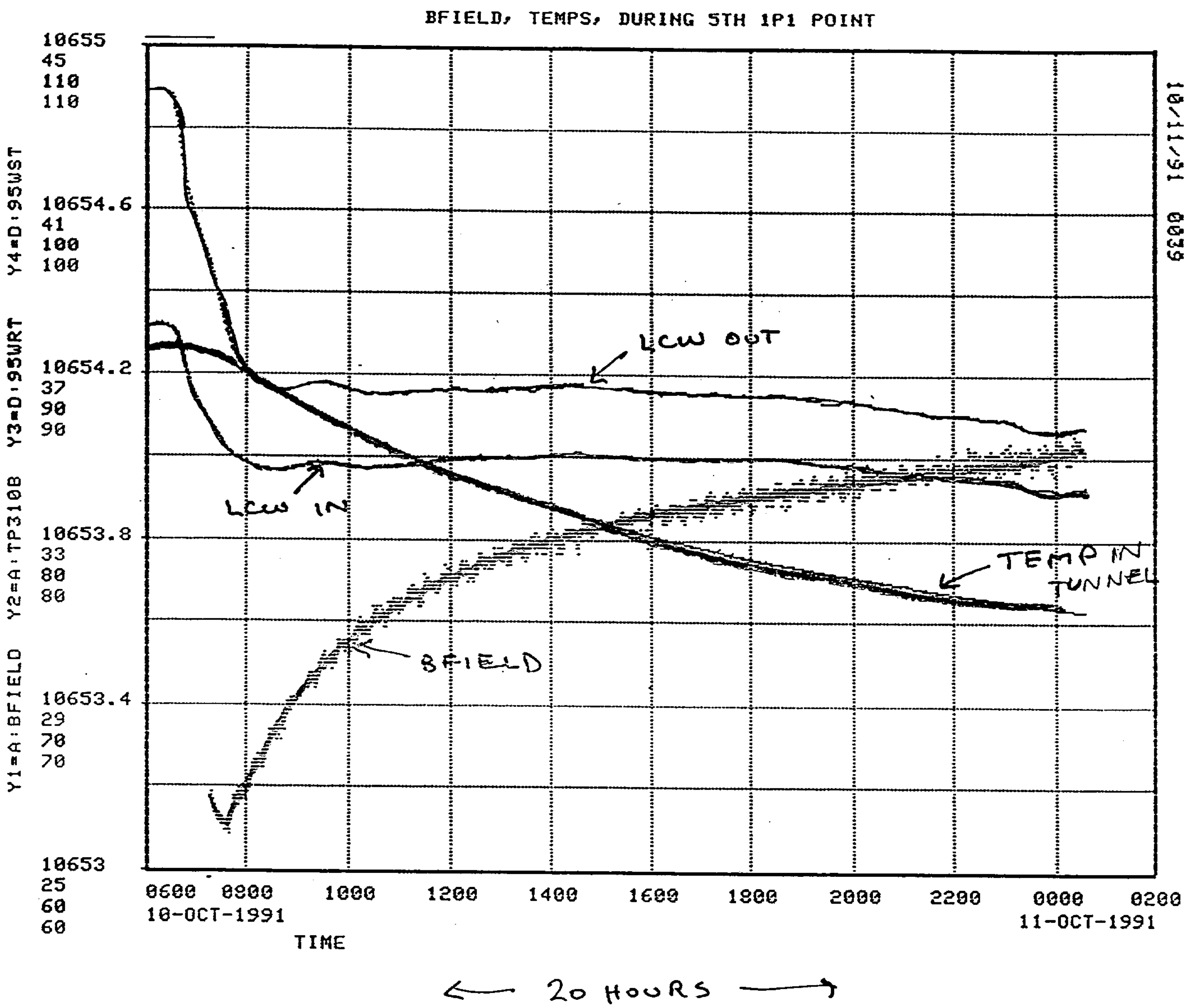
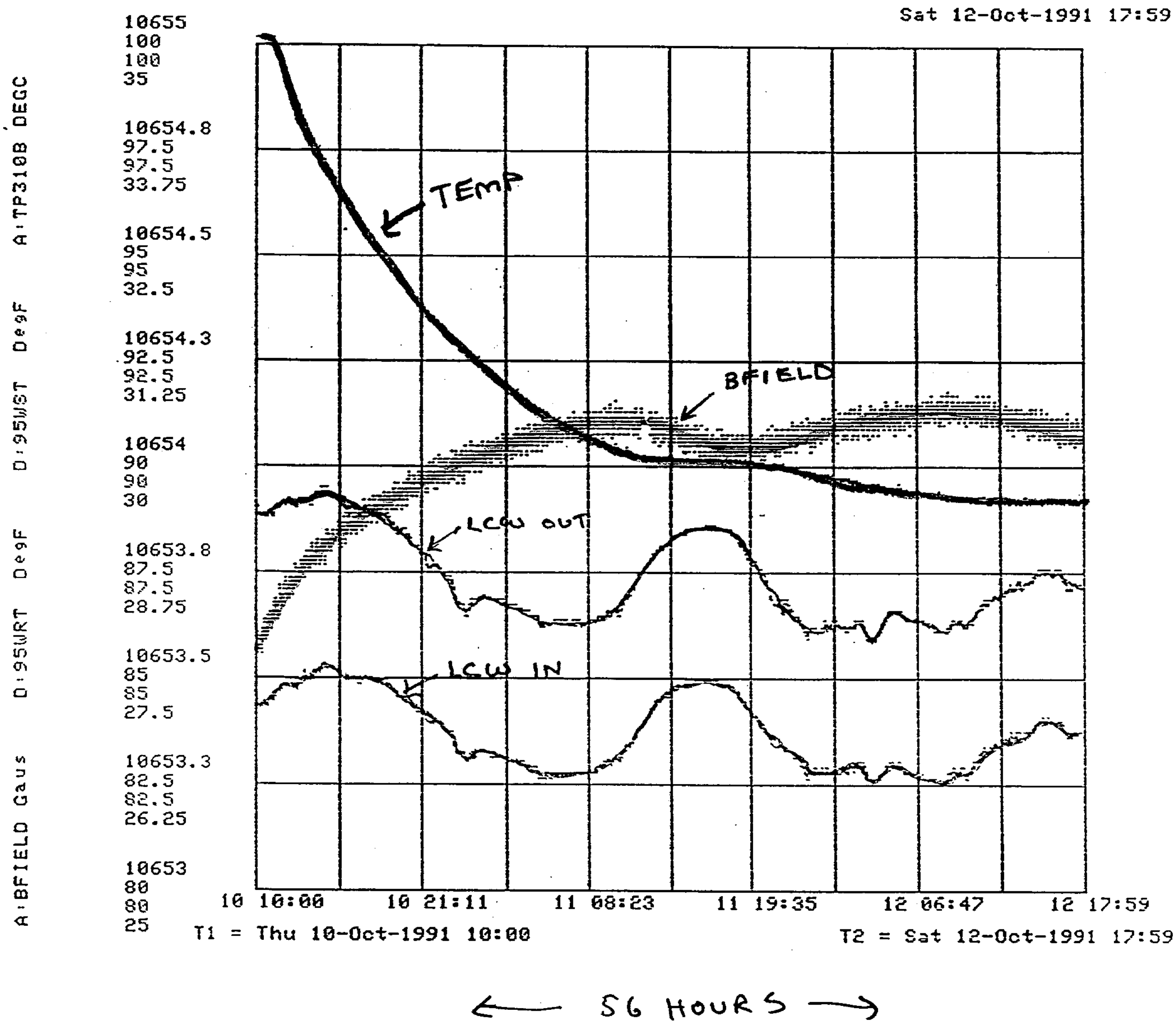


Fig. 13 Temperature and Bfield vs. time

CONSOLE LOCATION 43, 12-OCT-1991 18:03
misc. during 5th 1p1



ΔTEMP = 6°C

ΔLCW = 20°F

ΔB = 1 GAUSS

Fig 14 Temperature and B field vs. time.

ACCUMULATOR CLOSED ORBIT (HORIZONTAL)

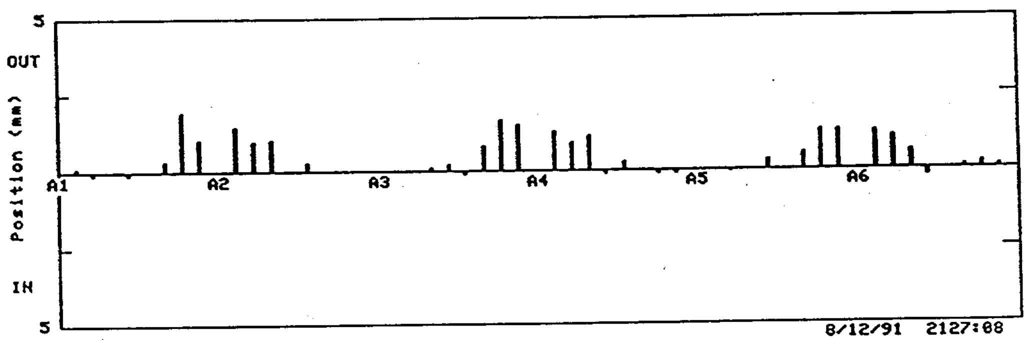
A:R1LLFS	52.39261	A:R3HLFB	5.967983
A:IBEAM	21.011	X:POFTT	5572.985

RECORD 95 CO Date/Time: 8/12/91 2125:09 1P1 1.247442958
MINUS AVG OVER 20 FRAMES (20 20 20 20 20 20)
RECORD 92 CO Date/Time: 8/12/91 0608:42 5572.985 1.2474429706 MHZ JET ON
AVG OVER 20 FRAMES (20 20 20 20 20 20)

Deltap/p = .0001

BEAM POSITIONS (mm)

A1Q1	.1	A2Q14	1.43	A3Q1	0	A4Q14	1.23	A5Q1	0	A6Q14	1.18
A1Q3	-.09	A2Q11	.93	A3Q3	0	A4Q11	.92	A5Q3	-.07	A6Q11	1.05
A1Q4	0	A2Q10	1.02	A3Q4	.09	A4Q10	1.11	A5Q4	0	A6Q10	.62
A1Q6	-.08	A2Q8	0	A3Q6	.18	A4Q8	-.09	A5Q6	.3	A6Q8	-.19
A1Q8	0	A2Q6	.25	A3Q8	-.09	A4Q6	.27	A5Q8	0	A6Q6	0
A1Q10	.28	A2Q4	0	A3Q10	.81	A4Q4	0	A5Q10	.53	A6Q4	.09
A1Q11	1.91	A2Q3	0	A3Q11	1.65	A4Q3	-.09	A5Q11	1.23	A6Q3	.2
A1Q14	1	A2Q1	0	A3Q14	1.51	A4Q1	-.11	A5Q14	1.29	A6Q1	.11



TYPICALLY $\frac{dL}{L}$ measured PREDICTED A $\frac{dB}{B}$

TWICE AS LARGE AS $\frac{dB}{B}$ measured ???

$$\frac{dp}{p} = \gamma_T^2 \frac{dL}{L} + \frac{dB}{B}$$

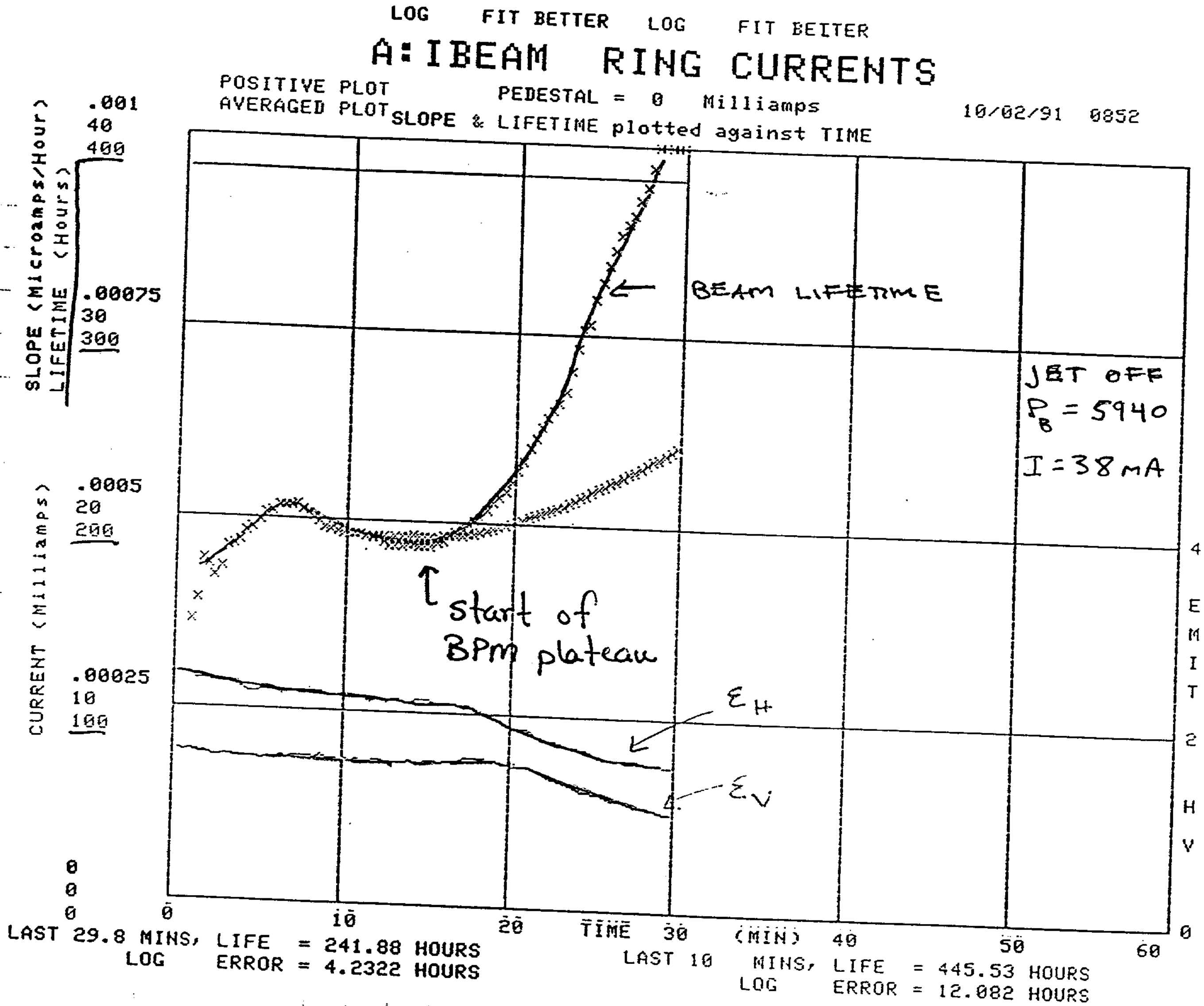
$$\frac{dp}{p} = \gamma^2 \frac{dF}{F} + \gamma^2 \frac{dL}{L}$$

$$\frac{dB}{B} = \gamma_T^2 \frac{dF}{F} + \frac{\gamma^2 - \gamma_T^2}{\gamma^2} \frac{dp}{p}$$

$$\frac{dB}{B} = \gamma^2 \frac{dF}{F} + (\gamma^2 - \gamma_T^2) \frac{dL}{L}$$

Fig 15: Orbit length change ~~[illegible]~~ due to temperature drift.

Prior to the BPM plateau we were having difficulty cooling the beam transversely. At the start of the BPM plateau both horizontal and vertical emittances started to drop and the beam lifetime increased dramatically. It ap[pears] that a small amount of RF helps the stochastic cooling process.



ION CLEARING ??

Fig. 16 Effect of bunching beam on transverse emittance

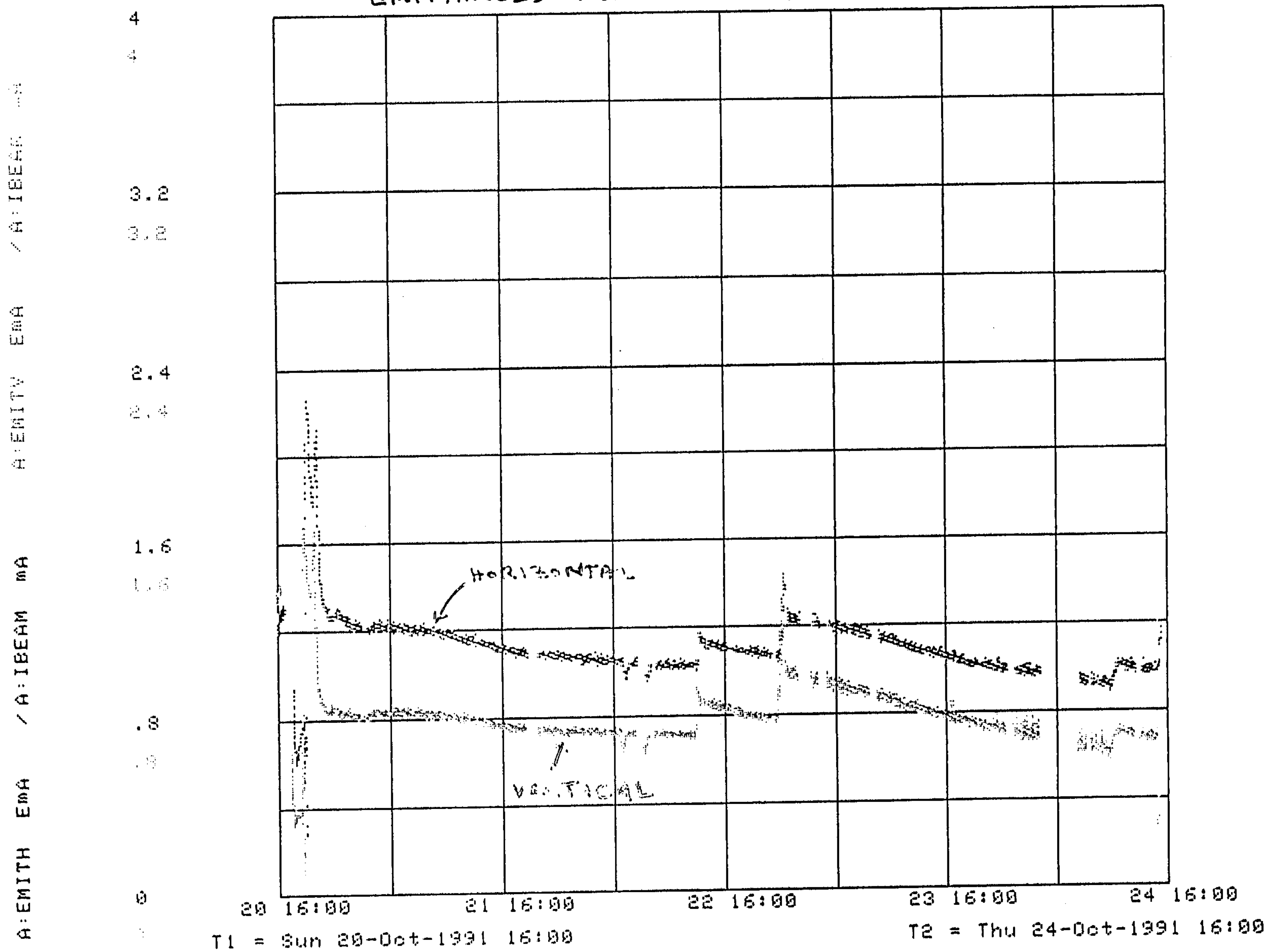
0925 Adjusted 4-8 GHz $\Delta P/P$ pick up position by equalizing the notch frequency and the average longitudinal Schottky frequency.

MULT:2	4-8 COOLING PICKUPS					
-A:MARAYD*.1	4-8 CORE M	-1.368	<	>	-2.486	mm ...
-A:MARAYU*.1	4-8 CORE M	-1.673	<	>	-2.791	mm ...

CONSOLE LOCATION 05, MCRLib 24-OCT-1991 22:23
[redacted]

Thu 24-Oct-1991 15:17

EMITTANCES FOR 6TH IP1



← 4 DAYS →

Fig-17. Typical transverse emittance during data taking